UNITED STATES PATENT APPLICATION

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for

RETARDED ELECTRIC MOTOR

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RETARDED ELECTRIC MOTOR

This application claims priority from pending German Patent Application No. 102 34 397.7 filed on July 23, 2002.

Background Of The Invention

[0001] The invention relates to a retarded electric motor comprising at least one field winding and a commutating armature being connected in series with the at least one field winding and being fed during operating mode by a supply voltage, and further comprising means for switching into a braking mode.

[0002] The invention further relates to an electric motor configured as an asynchronous motor comprising a squirrel cage rotor.

[0003] A retarded electric motor as mentioned at the outset and designed as a series motor is known from WO 91/03866.

[0004] Herein, for braking the series motor, a closed circuit disconnected from the power supply is formed via the field windings, commutating windings and the armature when switching from operating mode into braking mode. For limiting the braking current, a connection is formed between the armature and a commutating winding, this being controlled by two Zener diodes connected inversely parallel.

[0005] For switching between operating mode and braking mode, a multiple pole reversing switch is necessary that must have a specific switching sequence to avoid a destruction of the switch by the forming of a light arc

when switching quickly back and forth between operating mode and braking mode.

[0006] From DE 3 636 555 A1 another series motor has become known which shall offer a self-excited braking when switching from operating mode into braking mode. To guarantee an initiation of braking, a capacitor is provided that is charged during operating mode by means of a diode. When switching into braking mode, the braking is initiated by discharging the capacitor.

[0007] Also this electric motor requires a special multiple pole switch which must be designed so as to reliably disconnect the current circuit from the supply voltage, before the braking circuit is closed via one field winding and the armature. In addition, the utilization of a capacitor is seen as a disadvantage, since only one single capacitor discharge is possible, to initiate braking of the motor. If this should not be sufficient to effect a reliable initiation of the braking mode, then also later no braking will be possible, once the capacitor is discharged.

[0008] US 5,828,194 to Canova discloses a control circuit of a DC series motor comprising two half bridges each with a respective switch with controlled opening and closing. The first half bridge connects a pole of the field winding to the battery and the second of the half bridge connects a pole of the armature to the battery. The control circuit is designed to feed power resulting from the braking operation back into the battery. To this end the armature must be pole reversed which is effected by contactors for reversing. However, the utilization of mechanical contactors for switching between an operating and a braking mode is considered a major disadvantage.

[0009] US 6,236,177 to Zick et al. discloses a braking and control circuit for a series motor used in an electric power tool. A triac in series with

the armature and field windings is controlled by a microcontroller for controlling the motor during operating mode and during braking mode. During braking mode the armature is bypassed by a triac also controlled by the microcontroller. However, since the design utilizes fast switching electronic components high excess voltages may arise there from which may impair the reliability of the motor.

[00010] In asynchronous motors comprising squirrel cage rotors, up to now no braking device has become known.

Summary Of The Invention

[00011] In view of this, it is a first object of the invention to disclose a retarded electric motor offering a reliable braking in a simple cost-effective way.

[00012] It is a second object of the invention to disclose a retarded electric series motor allowing a switching between an operating mode and a braking mode without utilizing any mechanical switch.

[00013] It is a third object of the invention to disclose a braking module designed for retrofitting into an existing electric series motor not designed for braking.

[00014] It is a forth object of the invention to disclose a retarded electric series motor having a high fail-safety.

[00015] It is a fifth object of the invention to disclose a retarded electric asynchronous motor having a squirrel cage rotor.

[00016] It is a sixth object of the invention to disclose a retarded electric series motor avoiding excess voltages resulting from fast switching electronic components.

[00017] It is a seventh object of the invention to disclose a retarded electric series motor avoiding any multiple pole switch requiring a specific switching sequence.

[00018] These and other objects of the invention are achieved with respect to a retarded electric motor configured as a series motor as mentioned at the outset in that the means for switching into braking mode allows for bypassing the armature and for an external excitation of at least one field winding by means of the supply voltage, when being in braking mode.

[00019] During operating mode, the known circuit of an electric motor having its armature and field winding(s) in series is provided. To effect braking, the circuit via the armature and the field winding(s) is interrupted and at least one field winding is externally excited by the supply voltage, while the armature is bypassed. Thus, according to the invention, the motor is operated as an externally excited direct current generator to effect braking.

[00020] In this way, a reliable initiation of the braking is always guaranteed. In addition, a special multiple pole switch having a specific switching sequence is not necessary any more. By contrast, the desired switchover between operating mode and braking mode may be reached purely electronically, if desired.

[00021] With respect to the asynchronous motor having a squirrel cage rotor, this object is achieved with an asynchronous motor having at least two, preferably three, field windings, preferably in star connection, by

providing means for switching into braking mode allowing a disconnection of at least two field windings from the supply voltage when switching into braking mode, wherein a controllable valve is connected between at least two field windings, the controllable valve acting as a free wheeling valve during braking and being open during operating mode, wherein at least one, preferably two, field windings are externally excited by means of the supply voltage via a controllable valve that is open during operating mode.

[00022] In total, the invention provides for a reliable braking of the electric motor in a particularly cost-saving way, while a high fail-safety is reached.

[00023] Basically, several options exist when the motor is designed a series motor, to effect a switchover according to the invention between operating mode, in which the armature and the field winding(s) are in series and fed by the supply voltage, and between braking mode in which the motor is operated as an externally excited direct current generator.

[00024] According to a first development of the invention, a free wheeling valve is provided for limiting the voltage across the at least one field winding during braking mode.

[00025] In this way, excess voltages are avoided which may, in particular, result from fast switching electronic components, in particular in cooperation with inductances.

[00026] According to another development of the invention, means is provided for limiting the excitation current through the at least one field winding during braking mode.

[00027] In this way it is avoided that the excitation current rises too high.

[00028] According to a preferred embodiment of the invention, the series motor is provided with a controllable valve for bypassing the armature and being connected across the armature during braking mode.

[00029] Also for controlling the excitation current through the at least one field winding, a controllable valve may be provided.

[00030] A valve in this application shall be regarded in general as a semi-conductor component having a suitable control, such as a triac, a thyristor, a transistor, in particular a field effect transistor, or the like. In the simplest case also a diode merely giving a preferred direction of current may be regarded as a valve.

[00031] Herein, in particular an optical coupling device, such as an optical diode in combination with an optical triac, may be provided for driving the valve. Thereby a decoupling is effected between the control circuit and the current circuit to be switched, in which the controllable valve is provided.

[00032] As far as desired also a switch having mechanical contactors or a relay could act as a valve.

[00033] According to a further development of the invention, the controllable valve connects the at least one field winding via a load resistance to the supply voltage when being in braking mode.

[00034] According to this very simple design, also a limitation of the external excitation via the at least one field winding is simply reached by means of a load resistance.

[00035] According to an improvement of this design, the controllable valve connects the at least one field winding via a load resistance and at least one excitation winding to the supply voltage.

[00036] Since the excitation is given by the product of the number of turns and the current, a higher excitation may be reached at a respective number of turns, even at a considerably smaller current. Therefore, the load resistance may be designed with a higher value, whereby the power loss is reduced.

[00037] For controlling the motor during operating mode, according to a further design of the invention, a phase current control may be provided, whereby a switch, preferably designed as a triac, being in series with the at least one field winding and the armature, is controlled.

[00038] According to another embodiment of the invention, for controlling the motor during operating mode, a transistor, preferably a field effect transistor, is provided, preferably being driven by a pulse duration modulation (PWM) and, preferably, being in series with the at least one field winding and the armature.

[00039] Such a circuitry can easily be used, if the supply voltage is a direct voltage.

[00040] In case alternating voltage is utilized as supply voltage, then the transistor lying in the motor current circuit, is, preferably, connected via a rectifier, in particular, via a bridge rectifier, to the supply voltage and to the at least one field winding and the armature, respectively.

[00041] If desired, also a transistor driven by a pulse duration modulation can be utilized for controlling the motor current during operating

mode as well as for controlling the braking current during braking mode, whereby the circuitry is simplified in general.

[00042] According to a further development of the invention, for controlling the motor during operating mode as well as during braking mode, a phase current control is utilized being driven by means of a switch configured, preferably, as a triac and being in series with the at least one field winding and the armature. Herein, the phase current control during braking mode only drives one half wave according to the necessary current direction during braking mode.

[00043] Thereby, fewer components are necessary. Also a space-saving arrangement at low losses can be reached.

[00044] If the electric motor according to the invention is designed as an asynchronous motor having a squirrel cage rotor, then the controllable valves may for instance be designed as triacs that each are in series with a diode.

[00045] Preferably, herein the valve acting as a free wheeling valve is operated at a current flow angle of 180° during braking mode, while the current flow angle of the valve for external excitation can be controlled to a value of # 180° during braking mode.

[00046] In this way, a simple control is provided for controlling the intensity of braking.

[00047] It will be understood that the above-mentioned and following features of the invention are not limited to the given combinations, but are applicable in other combinations or taken alone without departing from the scope of the invention.

Short Description Of The Drawings

[00048] Further features and advantages of the invention will become apparent from the following description of preferred embodiments taken in conjunction with the drawings. In the drawings show:

[00049] Fig. 1 a first embodiment of an electric motor according to the invention being designed as a series motor, shown in extremely simplified representation;

[00050] Fig. 2 an electric motor according to Fig. 2 during braking mode;

[00051] Fig. 3 a further embodiment of a series motor according to the invention in extremely simplified representation;

[00052] Fig. 4 another embodiment of a series motor according to the invention utilizing a load resistance for limiting the excitation current;

[00053] Fig. 5 a modification of the embodiment according to Fig. 4, wherein, in addition, a supplementary excitation winding is provided, that is excited by means of the current flowing in the armature circuit during braking mode;

[00054] Fig. 6 a further modification of the embodiment according to Fig. 4, wherein, in addition, a supplementary excitation winding is provided in series with the load resistance;

[00055] Fig. 7 a further embodiment of a series motor according to the invention, wherein, for operating with direct current, a valve configured as a field effect transistor is provided for controlling the motor current during

operating mode as well as for controlling the braking current during braking mode;

[00056] Fig. 8 a modification of the embodiment of Fig. 7 for operation with alternating current;

[00057] Fig. 9 a further modification of the series motor according to the invention comprising a phase current control for a operating mode and a pulse duration control for braking mode, given a symmetrical arrangement of the armature between two field windings;

[00058] Fig. 10 a modification of the embodiment according to Fig. 9 utilizing an asymmetric arrangement of the field windings;

[00059] Fig. 11 an embodiment of the circuitry of Fig. 9, reduced to practice, wherein both valves V_2, V_3 are configured as triacs driven by optical triacs;

[00060] Fig. 12 a modification of the embodiment according to Fig. 8, wherein instead of a pulse modulation control a phase current control is utilized for operating mode as well as for braking mode;

[00061] Fig. 13 a modification of the embodiment of Fig. 10, having two diodes and only one controllable valve for braking control, shown in asymmetric configuration;

[00062] Fig. 14 a modification of the embodiment of Fig. 13, shown in symmetric configuration; and

[00063] Fig. 15 an embodiment of an asynchronous motor according to the invention, comprising three poles and a braking circuitry having controllable valves.

Detailed Description Of The Preferred Embodiments

[00064] An electric motor according to the invention may be utilized advantageously for instance for driving a retarded power tool, such as for operating a retarded angle grinder, a saw or the like.

[00065] In the beginning, the basic principle of the invention shall be discussed with respect to a series motor according to the invention, shown in Figs. 1, 2 and 3 in simplified manner.

[00066] While Fig. 1 depicts a series-wound motor 10 during operating mode, Fig. 2 depicts the series-wound motor 10' during braking mode.

[00067] The series-wound motor 10 or 10', respectively, comprises two field windings 14, 16 and an armature 12, which comprises an armature winding connected in a known manner via brushes that are depicted only schematically in Figs. 1 and 2.

[00068] The armature 12 is connected between the two field windings 14, 16 in series and may be connected via a switch S_1 (motor switch) with a supply voltage 17. In addition, a main switch S_0 may be provided for switching the complete motor on or off, being connected to supply voltage 17. Up to now, this is the known configuration of a series motor with a symmetric arrangement of the armature 12 between two field windings 14, 16.

[00069] According to the invention, now the possibility is provided to modify the series-wound motor 10 for braking in such a way that the arrangement of an externally excited direct current generator is reached, as shown in Fig. 2.

[00070] To this end, initially the current circuit via the two field windings 14, 16 and the armature 12 is interrupted by opening switch S_1. In addition, the armature 12 is shortened by means of a switch S_2 in parallel thereto, while the field winding 14 is connected via a switch S_3 to the other pole of the supply voltage, so that an external excitation results. It should be understood that the switches S_2, S_3 are open during operating mode, as to be seen from the representation of Fig. 1.

[00071] Since the series motor according to the invention is operated as an externally excited direct current generator, problems that occur with self-excited braking according to the prior art are completely avoided.

[00072] A generalized embodiment of the series motor 10 or 10', respectively, of Figs. 1 and 2 is depicted in Fig. 3 and denoted in total with reference numeral 10a.

[00073] Again, the series motor 10a comprises an armature 12 and two field windings 14, 16 arranged in series. While in Fig. 3 a symmetric arrangement of the armature 12 is shown, wherein also the armature 12 is arranged between the two field windings 14, 16, basically also an asymmetric arrangement is possible, wherein the two field windings 14, 16 would be connected with each other and coupled at one end via the armature 12 to the supply voltage.

[00074] The switches S_1, S_2, S_3 shown in Figs. 1 and 2 are shown in Fig. 3 in generalized form as any components that allow to control a current. Herein this may mean a complete disconnection, such as by means of a mechanical switch or a relay, or may mean a complete turning on, or any intermediate value. Therein, possibly a current limitation may be effected by means of a resistance or an inductance. Utilizing a semiconductor having a

suitable control, such as a triac, a thyristor, a transistor, in particular a field effect transistor, such a module can be effected utilizing electronic means only.

[00075] In addition to the embodiment according to Figs. 1 and 2, the series motor 10a according to Fig. 3 comprises a further module S_4 that is connected in parallel to one field winding 14 and serves to limit the voltage across field winding 14 which may occur depending on the specific embodiment of module S_3. In case module S_3 should include fast electronic switches, such as a pulse duration modulation, then this may lead to detrimental voltage surges that can be limited by module S_4. Therefore, S_4 generally depicts a free wheeling valve for limiting voltage surges. This may be a diode in the simplest case.

[00076] After completion of braking, S_3 may be opened to completely disconnect the circuit from the supply voltage. This is applicable for all embodiments of the invention.

[00077] A series motor according to the invention may be designed cost-effectively and reliably by utilizing only few electronic components, as will be discussed with reference to the embodiments according to Figs. 1 to 15 in the following.

[00078] Herein, the design may be chosen such that the braking electronics is separated from the motor electronics such that an existing motor may retrofitted with a braking circuitry. Practically, only one signal line between the motor electronics and braking electronics is necessary to activate the braking mode. For explanation, in the following designs the braking electronics is shown as a braking module 20 separately emphasized by a dashed line.

[00079] Herein, in different embodiments like reference numerals are utilized for similar parts whenever suitable.

[00080] In Fig. 4, a first one of these embodiments is depicted in total with reference numeral 10b.

[00081] The motor 10b comprises an armature 12, which is arranged symmetrically between two field windings 14, 16 in series. While one field winding 14 is directly connected to one pole of the supply voltage 17 at its end opposite the armature 12, the other field winding 16, at its end opposite the armature 12, is connected to the second pole of the supply voltage 17 by means of a valve V_1 that is configured as a triac. The valve V_1 is driven via a phase current control 18, as generally known in the art. Up to now, this circuitry corresponds to a series motor having field windings 14, 16, armature and triac V_1 with phase current control 18 according to the prior art, shown in operating mode.

[00082] Now, according to the invention, a braking module designated in total with reference numeral 20 is provided, including two valves V_3, V_4 and a load resistance R_1. The valve V_3 is connected across the armature 12, the valve being configured in this case as a thyristor which may, for instance, be driven by an optical coupling device (not shown). The valve V_3 allows to bypass the armature winding 12 in the manner discussed with respect to Figs. 2 and 3. In addition, the valve V_4 is connected between the armature 12 and the field winding 14, the valve connecting the field winding 14 from one pole of the supply voltage 17 via a load resistance R_1 to the other pole of the supply voltage 17. The excitation current flows herein during braking mode.

[00083] Also this valve V_4 may, for instance, be configured as a thyristor which may be driven by an optical coupling device (not shown).

[00084] When switching into the braking mode, firstly the valve V_1 is opened and the valves V_3, V_4 are switched on. Thus, the armature 12 and the valve V_3 are shortened and the field winding 14 is externally excited by means of the supply voltage 17 via the valve V_4 and the load resistance R_1. Since both valves V_3, V_4 are also connected with their anodes between armature 12 and field winding 14, the reversal of the current flow direction within the armature is automatically provided when switching into braking mode.

[00085] While the two valves V_1 and V_3 may be on/off switches in the easiest case, the valve V_4 is configured as a switching element having a preferred direction, namely at least a mechanical switch or a relay in series with a diode. However, preferably the valve V_4 is configured as an electronic component having a preferred direction and being switchable, such as a thyristor. The load resistance R_1 serves to limit the excitation current and may, for instance, be configured as a load resistance of about 150 watts, if the series motor 10b is, for instance, configured as a retarded universal motor having a power of about 1,000 watts.

[00086] A modification of the series motor of Fig. 4 is depicted in Fig. 5 and designated in total with numeral 10c.

[00087] The single difference with respect to the series motor 10b rests in the fact that in the embodiment of Fig. 5, an additional excitation winding L_1 is connected in series with valve V_3. By means of this additional excitation winding, in which the armature current flows during braking mode, the braking effect is enhanced. Due to this reason, the excitation current flowing via the field winding 14, the valve V_4 and the load resistance R_1 can be reduced during braking mode, thus the load resistance R_1 may be designed with a larger resistance value, so that the power loss acting there-across is reduced.

[00088] A further modification of this embodiment is shown in Fig. 6 and designated in total with numeral 10d. The single difference with respect to the embodiment of Fig. 5 rests in the fact that instead of an additional excitation winding L_1, now an additional excitation winding L_2 lying in series with the valve V_4 and the load resistance R_1 is provided.

[00089] Also in this way a stronger excitation is effected during braking mode, for which a smaller excitation current is sufficient.

[00090] A further embodiment of the series motor according to the invention is shown in Fig. 7 and designated in total with numeral 10e.

[00091] The circuitry shown is designed for operation with direct current, whereby a simplified design is reached. By contrast to the embodiments described before, herein both field windings 14, 16 are arranged asymmetrically with respect to the armature 12, which basically is also always possible with respect to the embodiments described before and to be described hereinafter.

[00092] For controlling the motor current as well as the braking current, a valve V_1 is provided being designed as a field effect transistor connected with source and drain to the negative pole of the supply voltage 17 and the armature 12, respectively. The field effect transistor is driven at its gate by means of a pulse duration modulation PWM.

[00093] Again, in parallel to the armature 12, a controllable valve V_3 is connected which may, e.g., be configured as a thyristor being connected with its cathode to drain of the field effect transistor V_1. To avoid excess voltages, which may arise from the fast switching of valve V_1 by means of the pulse duration modulation, between drain of valve V_1 and the positive pole of the supply voltage 17, a valve V_2 is connected serving as a free wheeling

valve. In the case shown, the valve V_2 is simply configured as a diode being connected with its cathode to the positive pole and with its anode to the cathode of valve V_3 and the armature 12 and drain of valve V_1, respectively.

[00094] The valve configured as the diode V_2 avoids the built up of excess voltages which might arise along the path formed by armature 12 and the two field windings 14, 16. During operating mode, the valve V_3 is switched off, and the power is controlled by valve V_1. When switching into braking mode, initially the valve V_1 is switched off and thereafter the valve V_3 is switched on with a time lag. Thereafter, the valve V_1 is switched on for the duration of the braking phase, e.g., for three seconds, until the motor is idle. Thereafter, V_1 and V_3 are switched off. Then the braking phase ends.

[00095] In Fig. 8, a modification of the circuitry according to Fig. 7, designed for operation with alternate current, is depicted and designated in total with numeral 10f. The armature 12 is arranged asymmetrically with respect to the two field windings 14, 16 and is connected with one pole of the supply voltage 17. The two field windings 14, 16 lying in series with the armature 12 are connected at one end thereof to a bridge rectifier 21, the other alternate current input of which is connected to the other pole of the supply voltage 17. The valve V_1, again configured as a field effect transistor, is driven at its gate by means of a pulse duration modulation PWM and is connected with its drain to the positive pole and with its source to the negative pole of the bridge rectifier 21.

[00096] For bypassing the armature 12, valve V_3 is connected in parallel thereto, while the valve V_2, which again serves as free wheeling valve, is connected in parallel to the two field windings 14, 16. The valves V_2, V_3, which again may be configured as thyristors, are poled in such a way that the two cathodes are connected with each other.

[00097] Again, during operating mode the two valves V_2, V_3 are inactive, so that the braking module 20 is without any effect. Thus, during operating mode the motor 10f is solely controlled by means of V_1 which is driven by means of the pulse duration modulation PWM. When switching into braking mode, initially the valve V_1 is switched off. Thereafter, the valves V_2, V_3 are switched on with a delay, and V_1 is switched on for the duration of braking, e.g. for 3 seconds, until the motor comes to a rest. Subsequently, V_1, V_2 and V_3 are switched off, this being the end of the braking phase.

[00098] A further embodiment of the motor according to the invention is shown in Fig. 9 and designated in total with numeral 10g.

[00099] Herein, a phase current control is utilized for controlling the motor 10f during operating mode, as also being the case with respect to the embodiments of Figs. 4 to 6.

[000100] For limiting the excitation current during braking mode, instead of a load resistance now a controllable valve V_5 being configured as a field effect transistor is utilized, being driven at its gate by means of a pulse duration modulation PWM.

[000101] In the case shown, again a symmetric arrangement of the armature 12 between the two field windings 14, 16 is shown. While the one field winding 14 is connected to one pole of the supply voltage 17, the other field winding 16 is connected at its end opposite the armature 12 to the other pole of the supply voltage 17 by means of a valve V_1 configured as a triac. The triac is driven by means of a phase current control 18.

[000102] For bypassing the armature winding 12 during braking mode, again a controllable valve V_3 is provided, while across the field winding 14 a controllable free wheeling valve V_2 is connected to limit any voltage

surges at the field winding 14. For controlling the excitation current during braking mode, the valve V_5 is provided which is configured as a field effect transistor and connected by means of a valve V_4 to the field winding 14 and to the armature 12 and the two valves V_2, V_3, respectively. If the pulse duration modulation PWM can be switched off, then the valve V_4 merely serves to provide the correct current direction to valve V_5. Therefore, it may be a diode in the simplest case. If the pulse duration modulation is not configured for switching off, then the valve V_4 is configured as a controllable valve, as well as the two other valves V_2, V_3, for instance as a thyristor. To guarantee a potential separation, again for driving the valves V_2, V_3 and possibly V_4, an optical coupling device may be utilized.

[000103] As can be seen from Fig. 9, the valves V_2, V_3, V_4 are each connected with its anode side between the field winding 14 and the armature 12.

[000104] During operating mode, the valves V_2, V_3, V_4, V_5 are switched off, so that the known configuration of a series motor results which is controlled by means of a triac V_1 in combination with phase current control 18. For switching into braking mode, initially V_1 is switched off by means of the phase current control 18, and the valves V_2, V_3 are switched on with a certain time delay. Thereafter, the valves V_4, V_5 are switched on for the duration of the braking phase, until the motor comes to a rest. Thereafter, the valves V_4, V_5 and V_2, V_3 are switched off, whereby the braking phase ends.

[000105] In Fig. 10, a modification of the series motor of Fig. 9 is shown with asymmetric configuration of the armature 12 and depicted in total with 10h. Apart from the asymmetric configuration, the design and operation of the motor 10h completely corresponds to the design described before with respect to Fig. 9. The armature 12 is connected to one pole of the supply voltage 17 and connected with its other end to the two field windings 14, 16

arranged in series. The end of the field winding 16 opposite the armature 12 is connected to the other pole of the supply voltage 17 by means of the valve V_1 being configured as a triac. For control, again a phase current control 18 is provided. For bypassing the armature 12, a controllable valve V_3, possibly being configured as a thyristor, is connected in parallel thereto. Across the two field windings 14, 16, the free wheeling valve V_2 is connected with its cathode to the cathode of valve V_3 and to the armature 12 and the field winding 14, respectively. For controlling the excitation current through the field windings 14, 16 and the valve V_3 during braking mode, again the valve V_5, configured as a field effect transistor, is provided and being driven by means of a pulse duration modulation PWM and being connected between the triac and the field winding 16 by means of a valve V_4. As described before, V_4 may be a simple diode, in case the pulse duration modulation PWM is configured for switch-off.

[000106] In Fig. 11, one possible reduction to practice of the motor of Fig. 9 is shown in more detail and depicted in total with 10i.

[000107] The basic configuration of motor 10i is completely identical to the circuitry of the motor 10g according to Fig. 9. Merely the valves V_2, V_3, and V_4, which according to Fig. 9 were merely shown schematically, are now depicted in their actual configuration.

[000108] V_4 is configured as a simple diode, since V_5 can be switched off by means of the pulse duration modulation PWM. The two valves V_2, V_3 are each configured as triacs, which each are driven by means of an optical triac.

[000109] The valve V_2 (free wheeling valve) comprises a triac 22 which is connected between the armature 12 and the field winding 14 by means of a diode 24 which is connected with its cathode to the supply voltage

17. For driving the triac 22, an optical triac 28 is provided which is connected to the gate of triac 22 on the one hand and to the connection with the anode of diode 24 via a resistor 26 on the other hand. The optical triac 28 is connected via a resistor 30 to the line 40 which is connected to the anode of valve V_4, the armature 12 and the field winding 14. The optical triac 28 is controlled by means of an LED.

[000110] In a corresponding manner, the valve V_3 for bypassing the armature 12 comprises a triac 32 being connected in parallel to armature 12 between the line 40 and the connection to field winding 16. A diode in this circuit is superfluous. Again, the triac 32 is driven by an optical triac 38 which is connected to the gate of triac 32, is coupled to the line 40 via a resistor 36 and is connected via a resistor 34 to the connection of triac 32 to armature 12 and field winding 16. Again, for driving the optical triac, an LED is utilized.

[000111] Basically, also the triacs 22, 32 themselves could be configured as optical triacs, in case components with sufficient power are readily available. In the current case, the triacs 22, 32 are configured as power triacs, while the optical triacs 28, 38 are merely configured as control elements of small power.

[000112] The operation of motor 10i according to Fig. 11 completely corresponds to the operation of motor 10g according to Fig. 9.

[000113] Needless to say, for example also the motor 10h of Fig. 10 could be designed in a corresponding manner with triacs and optical triacs, respectively, as previously described with respect to Fig. 11.

[000114] A modification of the embodiment of Fig. 8 is depicted in Fig. 12 and designated in total with 10j.

[000115] Herein, the pulse duration modulation of Fig. 8 was replaced by a phase current control 18. The latter controls the valve V_1, now being configured as a triac, during operating mode as well as during braking mode. Naturally, the rectifier 21 is deleted herein. With respect to the reminder, the operation of this configuration completely corresponds to the operation explained before with respect to Fig. 8.

[000116] During operating mode, triac V_1 is typically driven with both half waves. Herein, the phase control angle α is between 90° and 180°. By contrast, during braking mode only the positive half wave is passed, for instance with α of 160°.

[000117] The configuration according to Fig. 12 utilizes less components with respect to the configuration of Fig. 8, is space saving and has lower losses.

[000118] A modification of the embodiment of the motor of Fig. 10 is shown in Fig. 13 and designated in total with 10k.

[000119] Herein, the circuitry was simplified with respect to the embodiment of Fig. 10 by providing a valve V_6, designed as a triac, connected between the wire connection between armature 12 or field winding 14, respectively, and the diodes V_2, V_3, the valve V_6 being driven by the control 42 of valve V_5 (PWM). In this case, the valves V_2, V_3 may be configured as simple diodes. Apart from this, the operation of this design completely corresponds to the one of Fig. 10.

[000120] In Fig. 14, a modification of the asymmetric design of Fig. 13 is shown as a symmetric design and designated in total with 10l. Apart from this, the operation completely corresponds to the design according to Figs. 11 and 13, respectively.

[000121] Needless to say, the control 42 for the PWM, shown in Figs. 13 and 14 separately, may be combined with the control 18 for V_1 and may, for instance, be configured as a microcontroller.

[000122] In Fig. 15, an embodiment of the electric motor according to the invention configured as an asynchronous motor is depicted and designated in total with 10m. The motor 10m is a 3-phase motor comprising three field windings 14, 15, 16, arranged in star configuration and fed by phases L_1, L_2, and L_3 from the supply voltage at a frequency of, e.g., 300 Hz. The armature is configured as a squirrel cage rotor not shown here.

[000123] Due to the frequency which is higher than the mains frequency of 50 Hz, such a motor is also designated as a HF motor when used with regard to power tools (not to be confused with high frequency in the sense of electromagnetic waves in the MHz range or higher). Such HF machines are used for electric power tools that are extremely loaded continuously, since due to the lack of brushes they are maintenance-free.

[000124] For switching the motor 10m on and off and for switching between operating mode and braking mode, a two-pole on/off switch S_1 having the poles 50 and 52 is provided. For braking the motor 10m, a braking circuit designated in total with 20 is provided. The braking circuit 20 comprises a valve V_8 lying in series with a diode 48, and by means of which the two field windings 14, 16 are connected in series between the two phases L_1 and L_3, and thus being externally excited by means of a pulsating direct voltage, when the valve V_8 is closed.

[000125] Simultaneously during braking mode, a valve V_7 acting as a free wheeling valve is closed across the two field windings 14, 16 via a line 54, the valve being in series with a diode 46. By means of the free wheeling valve V_7, a further rotation of the motor 10m is avoided during braking mode.

[000126] As shown, the two valves V_7, V_8 may be designed as triacs driven by means of a control 44.

[000127] During operating mode, both valves V_7, V_8 are open and the switch S_1 is closed, so that the known circuit of a 3-phase asynchronous motor in star connection is given. For switching into braking mode, the switch S_1 is opened and both valves V_7, V_8 are closed. While the valve V_7 is fully opened, i.e. is operated at a phase current angle of 180°, the phase current angle of the valve V_8 is, preferably, regulated by means of the control 44 to an intended value between 0° and 180°, to allow a control of the braking.

[000128] It will be understood that the valves V_7, V_8 may also be chosen as valves controllable in any other way, such as transistors, in particular field effect transistors.